Environmental Fluctuations and Acoustic Data Communications

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LONG-TERM GOALS

Couple together analytical and numerical modeling of oceanographic and surface wave processes, acoustic propagation modeling, statistical descriptions of the waveguide impulse response between multiple sources and receivers, and the design and performance characterization of underwater acoustic digital data communication systems in shallow water.

OBJECTIVES

Develop analytical/numerical models, validated with experimental data, that relate short-term oceanographic variability and source/receiver motion to fluctuations in the waveguide acoustic impulse response between multiple sources and receivers along with new communication receiver algorithms that exploit these channel characterizations.

APPROACH

The focus of this research is on how to incorporate an understanding of short-term variability in the oceanographic environment and source/receiver motion into the design and performance characterization of underwater acoustic, diversity-exploiting, digital data communication systems. The underlying physics must relate the impact of a fluctuating oceanographic environment and source/receiver motion to fluctuations in the waveguide acoustic impulse response between multiple sources and receivers and ultimately to the design and performance characterization of underwater acoustic digital data communication systems in shallow water.

The two major thrusts of this work include participation in a shallow water acoustic communication experiment in June-July 2011 along with subsequent analysis of the experiment data.

KAM11 Experiment (2011)

A shallow water acoustic communications experiment (KAM11) was carried out in June-July 2011 off the western side of Kauai, Hawaii at the Pacific Missile Range Facility (PMRF). Both fixed and towed source transmissions were carried out to multiple receiving arrays over ranges of approximately 1-14 km. Substantial environmental data was collected including water column sound speed structure

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(CTDs and thermistor strings), sea surface directional wave field (waverider buoy), and local wind speed and direction. The focus was on fluctuations over scales of a few seconds to a few tens of seconds that directly affect reception of a data packet and packet-to-packet variability.

Algorithm Design and Experiment Data Analysis

Communication receiver algorithm design for shallow water is challenging due to the likelihood of encountering highly dynamic environments. In fact, one of the reasons for the KAM11 site selection was the variability of the environmental conditions (both sea surface and water column) from fairly calm to highly fluctuating. One emphasis of our work is mitigating Doppler and Doppler spread (both due to source-receiver motion as well as a fluctuating sea surface). Another emphasis of our work is multi-user receiver design in the presence of unsynchronized users (to accommodate networked communication). Lastly, a third emphasis of our work is communication algorithm design for very low signal-to-noise ratio (SNR) operations.

WORK COMPLETED

A shallow water acoustic communications experiment (KAM11) was conducted in early summer 2011 off the western side of Kauai, Hawaii [8]. Both fixed and towed source transmissions were carried out to multiple receiving arrays over ranges of 1-8 km along with additional towed source transmissions out to 14 km range. The acoustic transmissions were in three bands covering 3.5 to 35 kHz. Substantial environmental data was collected including water column sound speed structure (CTDs and thermistor strings), sea surface directional wave field (waverider buoy), and local wind speed and direction. The focus was on fluctuations over scales of a few seconds to a few tens of seconds that directly affect the reception of a data packet and packet-to-packet variability. The experiment region exhibited substantial daily oceanographic variability.

Analysis of the KAM11 experiment data this past year has focused on fixed source transmissions. Specifically, data investigating the influence of surface interacting ray paths compared to refracting ray paths was analyzed.

Publications related to this research involving analysis of KAM11 (and previous KAM08) data include [1-14].

RESULTS

During KAM11, a two-day period was devoted to wideband transmissions. Specifically, wideband channel impulse response transmissions (24 kHz bandwidth LFM chirps and MLSs centered at 23 kHz) were carried out every 2 hours for an extended period of time. These were transmitted from a moored 8-element source array with 7.5 m element spacing and carried out in a round-robin fashion for 60 s per source element. A pair of 16-element receive arrays with 3.75 m element spacing were moored at ranges of 3 and 7 km from the source array (see Fig. 1). The fixed source, fixed receiving array geometry enabled observing environmentally-induced fluctuations in the channel impulse response [11, 14].

The multipath structure at 0351 UTC predicted using the Bellhop ray tracing code from Source 1 to Receivers 1 and 3 is shown in Fig. 2. The sound speed profile has a mixed layer depth of ~35 m then a negative gradient thermocline extending to the bottom. As a result, higher-angle ray paths interact with

the sea surface while lower-angle ray paths are ducted as near-seafloor refracting rays. The single surface reflecting paths arrive first at the array while the deep refracting rays arrive later.

The wideband (10-34 kHz LFM chirps, 48 ms in duration repeated every 96 ms) time-evolving (over 60 s) channel impulse response (CIR) is shown in Fig. 3 for the deepest source (Source 1) to two deep receiving array elements (Receivers 1 and 3) at a range of 3 km from the source array. The first few arrivals (44-47 ms) correspond to single surface-reflecting paths (the bulk travel time has been removed from these CIR plots). In an effort to remove any residual mooring motion, Fig. 3 is obtained from resampled time series data using as a reference the deep refracting paths arriving at 48.43 ms and 48.21 ms, respectively. The relatedness of fluctuations between pairs of paths is summarized by the path-path covariance matrices. These are shown in Fig. 4 for the individual receivers and in Fig. 5 for the cross-receiver case. These covariance matrices then can be used for tapped delay line channel model simulation purposes [3].

IMPACT / APPLICATIONS

Acoustic data communications is of broad interest for the retrieval of environmental data from in situ sensors, the exchange of data and control information between AUVs (autonomous undersea vehicles) and other off-board/distributed sensing systems and relay nodes (e.g. surface buoys), and submarine communications.

RELATED PROJECTS

In addition to other ONR Code 322OA and Code 321US projects investigating various aspects of acoustic data communications from both an ocean acoustics and signal processing perspective, two recently completed MURIs also focused on acoustic communications (W. Hodgkiss, “Impact of Oceanographic Variability on Acoustic Communications” and J. Preisig, “Underwater Acoustic Propagation and Communications: A Coupled Research Program”).

PUBLICATIONS

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[14] W.S. Hodgkiss, H.C. Song, and D.E. Ensberg, “Statistical characterization of wideband channel impulse response observations in shallow water,” Proc. 2nd Intl. Conf. Underwater Acoustics (UA2014): 1535-1540, ISBN: 978-618-80725-1-0 (2014). [published]

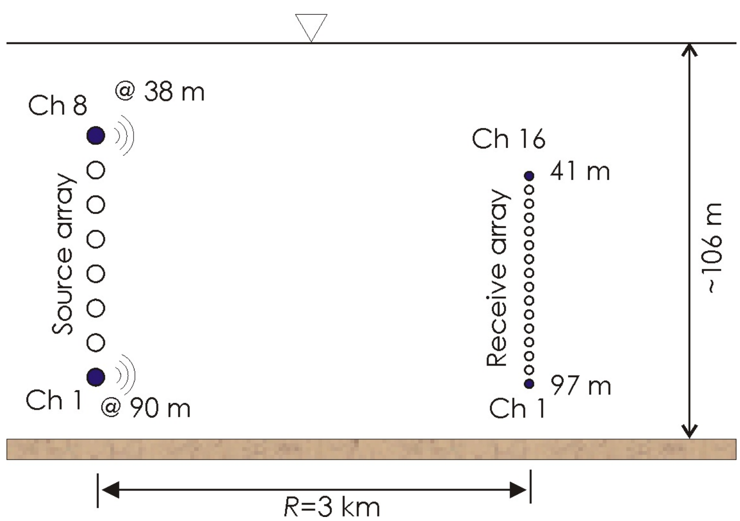


Figure 1. KAM11 experiment source and receive array (R = 3 km) configuration during collection of wideband transmission data. Source array element spacing was 7.5 m and receive array element spacing was 3.75 m.

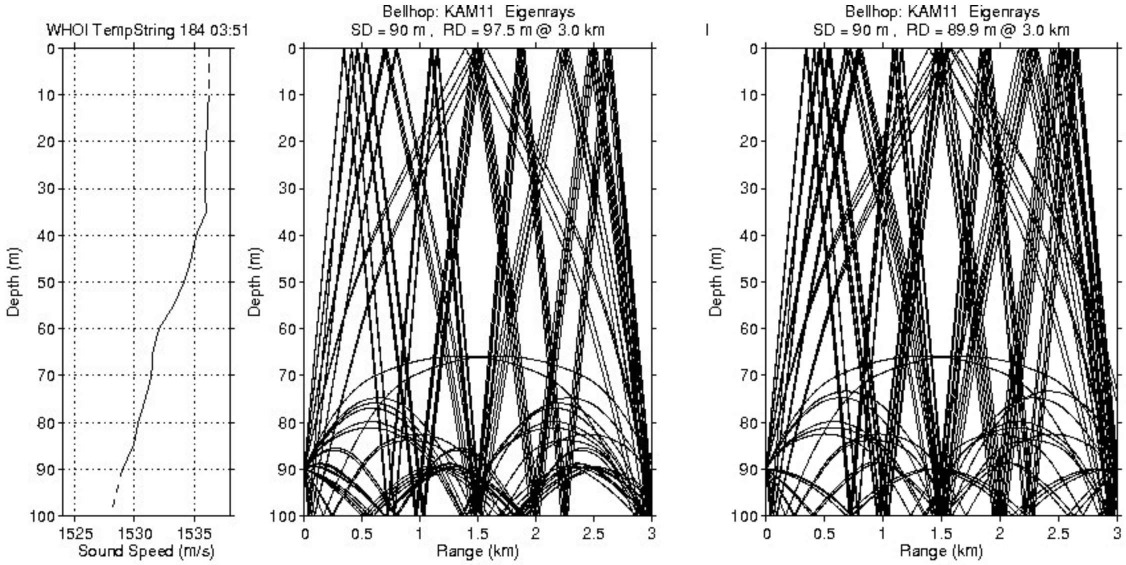


Figure 2. Multipath structure at 0351 UTC on JD 184: (a) sound speed profile, (b) eigenray paths from Source 1 to Receiver 1, and (c) eigenray paths from Source 1 to Receiver 3. The single surface reflecting paths arrive first at the array while the deep refracting rays arrive later.

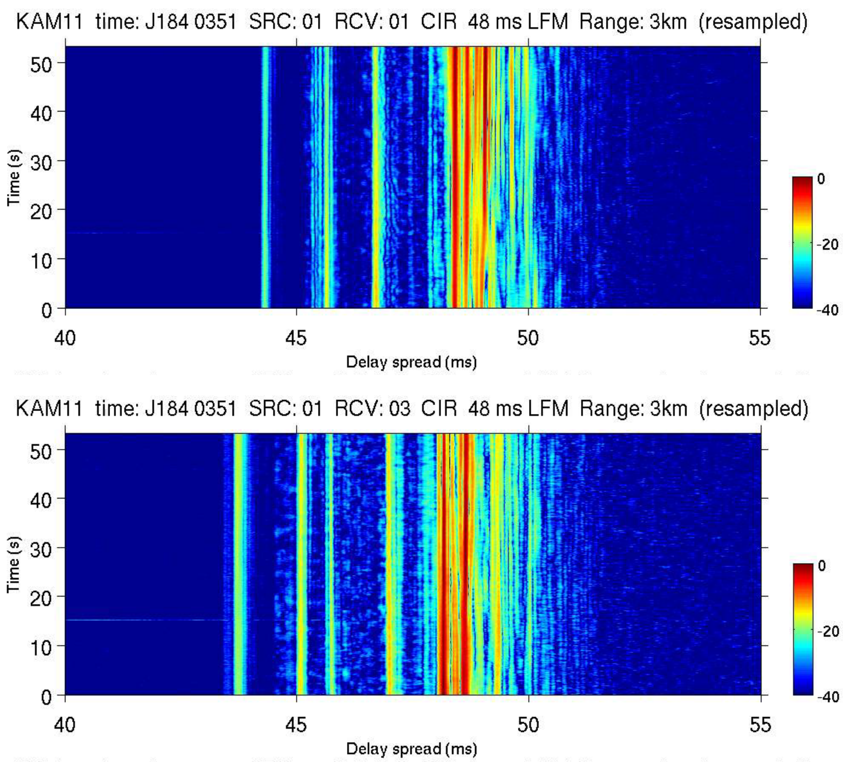
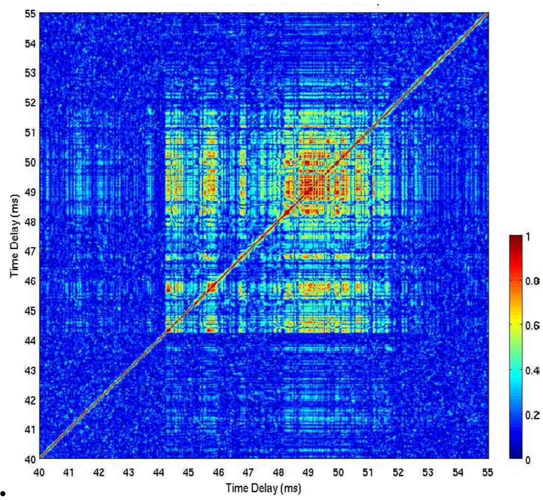


Figure 3. Wideband time-evolving channel impulse response on JD 184 0351 UTC: (a) Source 1 to Receiver 1 and (b) Source 1 to Receiver



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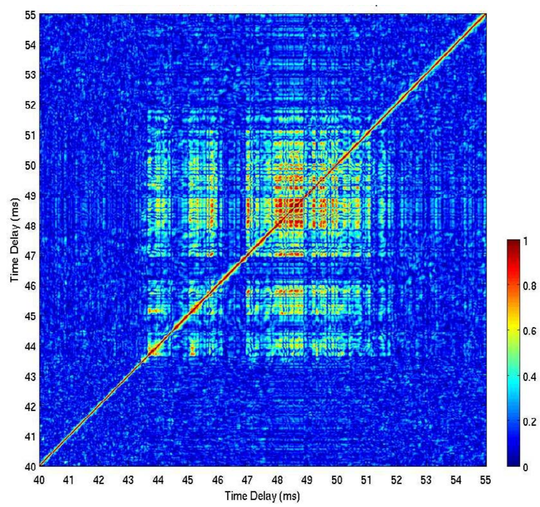

Figure 4. Wideband path-path normalized covariance matrix on JD 184 0351 UTC: (a) Receiver 1 and (b) Receiver 3.

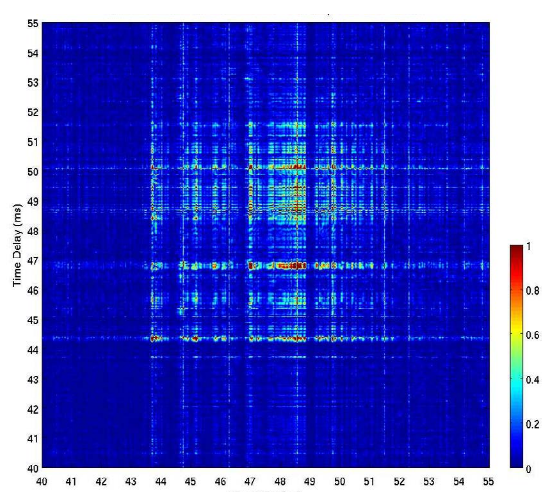

Figure 5. Wideband path-path normalized cross-covariance matrix on JD 184 0351 UTC: Receiver 1 (vertical axis) and Receiver 3 (horizontal axis).